Cluster 1

Collaborating Hearing Aids: An Information-Theoretic Perspective

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Motivations

What are hearing aids? Acoustic sensing devices that aim at compensating various kind of hearing impairments.

- Examples of processing done at hearing aids:
  - Spectral shaping (frequency attenuation/amplification).
  - Beamforming.
  - Noise reduction.
- Types of hearing aids: (a) behind-the-ear (BTE), (b) in-the-ear (ITE), (c) in-the-canal (ITC) and (d) completely-in-the-canal (CTC).

(a) (b) (c) (d)

- Most state-of-the-art systems involve two independently working devices.
- Problems:
  - Small spatial extent between microphones.
  - Limited beamforming capability.
  - Poor rejection of interfering signals.
  - Reduced speech intelligibility in noisy environments.
- Solution: to allow collaboration between the hearing aids using a rate-constrained wireless link.
- Goal of this work: to characterize the optimal tradeoff between the communication bit-rate and the beamforming gain provided by this collaboration.

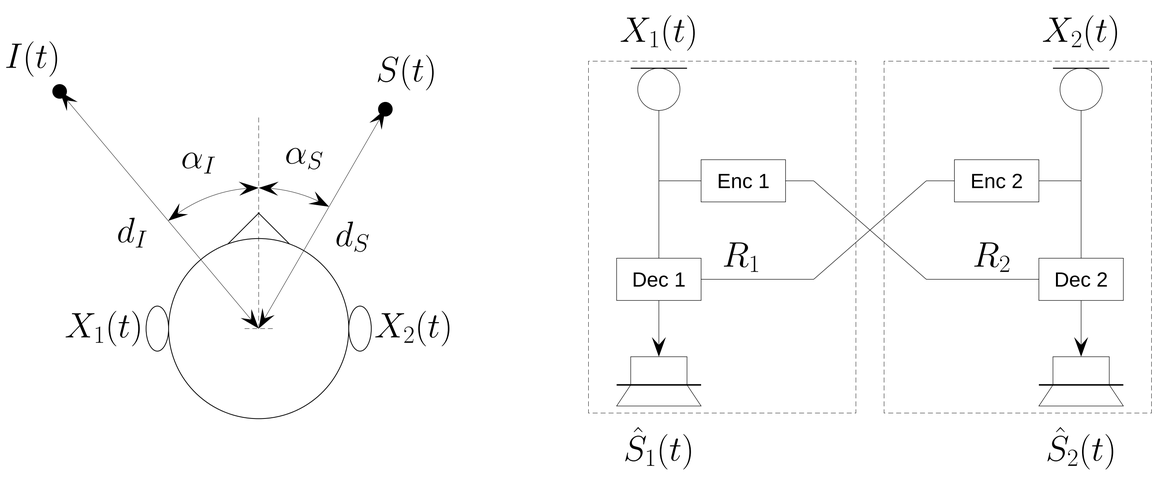
Problem Setup

- The auditory scene: a desired source $S(t)$, an interferer $I(t)$ and some ambient noise [see Figure 1(a)].
- The signal observed at hearing aid l ($l = 1, 2$) can be written as

$$X_l(t) = h_l(t) * S(t) + g_l(t) * I(t) + N_l(t)\,,$$

where $h_l(t)$ and $g_l(t)$ are linear and time-invariant filters (e.g. room impulse responses or head-related impulse responses).

- The two hearing aids are allowed to collaborate using a wireless communication link [see Figure 1(b)].

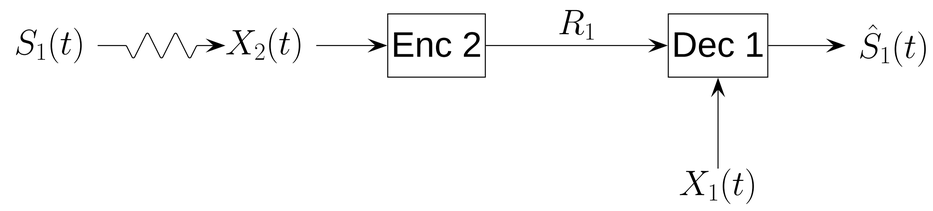


(a) (b)

Fig. 1: The hearing aid setup. (a) Typical head-related configuration. (b) Collaboration using a wireless communication link.

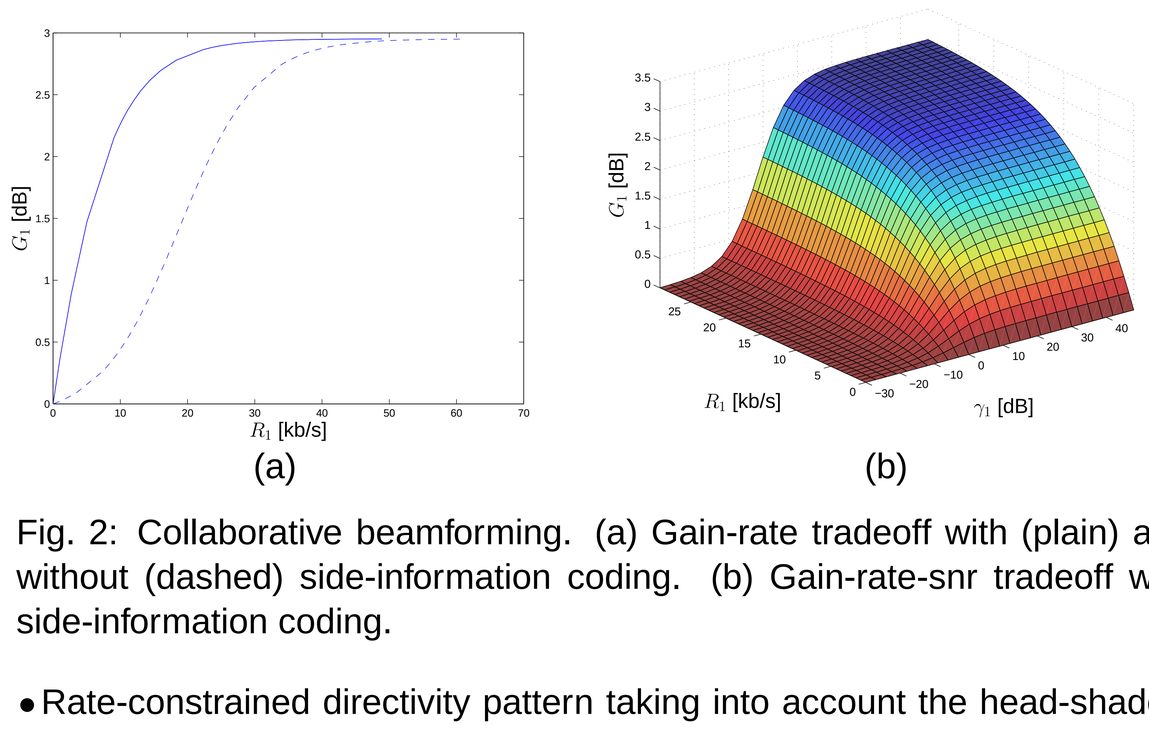
Information-Theoretic Framework

- We adopt the perspective of hearing aid 1.
- Remote source coding problem with side information at the decoder.



Results

- Optimal gain-rate tradeoffs for a source in ambient noise (see Figure 2).



(a) (b)

Fig. 2: Collaborative beamforming. (a) Gain-rate tradeoff with (plain) and without (dashed) side-information coding. (b) Gain-rate-snr tradeoff with side-information coding.

- Rate-constrained directivity pattern taking into account the head-shadow effect (see Figure 3).

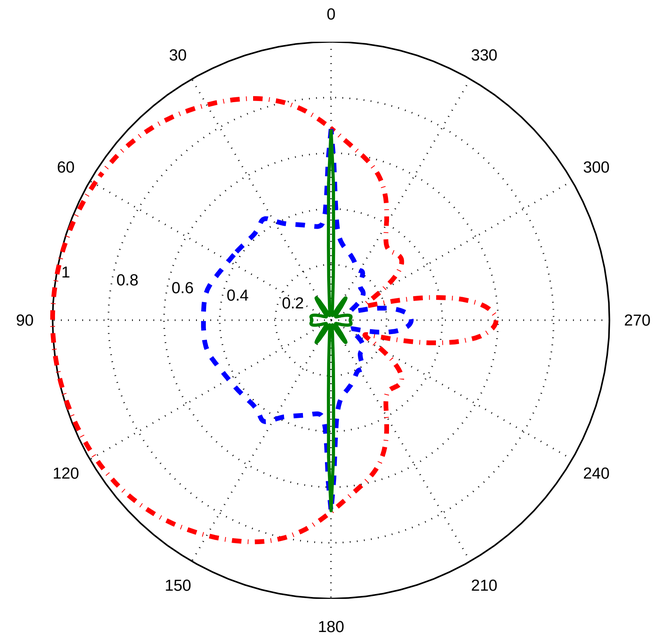


Fig. 3: Rate-constrained directivity pattern at $f = 3000[Hz]$ and $R_1 = 0$ (dash-dotted), $R_1 = 0.1$ (dashed) and $R_1 = 1$ (solid) [b/s/Hz].

References

[1] O. Roy and M. Vetterli, "Collaborating hearing aids," *MSRI Workshop on Mathematics of Relaying and Cooperation in Communication Networks*, April 2006.

[2] O. Roy and M. Vetterli, "Rate-constrained beamforming for collaborating hearing aids," *IEEE International Symposium on Information Theory*, pp. 2809–2813, July 2006.

FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
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Swiss National Science Foundation

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